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Memorandum

24 June 2010

To: Mike Gerardi

From: Bill Higgins

Subject: Groundwater and Surface Water Activity in MuCOOL Beam Operation

The limit for tritium, H^3, in surface water is 2000 pCi/ml and for sodium-22, Na^{22}, it is 10 pCi/ml.

For groundwater, the tritium limit is 20 pCi/ml and the sodium-22 limit is 0.4 pCi/ml.

Surface Water Activity Due to MuCOOL Emittance-Measurement Mode

The emittance-measurement mode in the MuCOOL beamline entails 600 pulses per hour of up to 1.6E13 protons per pulse, stopping in the emittance absorber in the MTA stub. We wish to know the constraints set by surface water activity limits on this mode of operation.

To estimate surface water activity, we need a star density in soil due to impact of beam on the emittance absorver. This is derived from MARS simulations. We then use a spreadsheet implementing the calculation method described in Reference 1.

Igor Rakhno wrote on 31 March:

"The [emittance absorber] itself is a 6" dia. and 66" long steel cylinder with a 5" dia. and 8" long copper insert in upstream part, according to the design provided by Tom [Kobilarcik]... The calculated distributions reveal the maximum value of about S_{max} = 5.9E4 star/(cm^3*sec) for the rep.rate of 1 Hz, so that you can easily scale the S_{max} according to an operation scenario under consideration."

This S_{max} value, quoted for beam parameters of 1 Hz (3600 pulses per hour) and 1.6E13 protons per pulse, therefore 1.6E13 protons per second, corresponds to

(5.9E4 stars/cm^3-sec)/(1.6E13 p/sec) = 3.69E-9 stars per incident proton per cubic centimeter.

Inserting this value into the groundwater model spreadsheet for S_{max}, and varying the number of incident protons per year, we can find the resulting surface water activity, expressed as a percentage of the surface water limit.

(For hydrological transport coefficient, or "R," we select 6.3E-9, which is a value used in previous studies of the MuCOOL region and is similar to coefficients used for Booster. This is not relevant to this particular study, because the area around MTA and its stub is flushed and collected in sumps. Therefore only surface water, not groundwater, is of interest.)

At what annual rate of total protons does the surface water activity hit 100% of the limit?

The answer turns out to be about 2.929E20 protons per year. (See Appendix 1.)

This represents about 18 million pulses of full Linac intensity, or a rate of about 2090 pulses per hour if beam is delivered all year long with no downtime.

Planned operation of beam to the emittance absorber will consist of up to 600 pulses per hour for occasional periods of a few hours at a time, or shorter. Therefore emittance measurement mode will be well within any limits set by surface water activity. For example, one hour per week at 600 pulses per hour and 1.6E13 protons per pulse would be 5E17 protons per year.

Emittance Mode Groundwater

If it is assumed that the drainage system does not flush radionuclides into surface water, instead percolating into deeper layers, the hypothetical effect on groundwater may be calculated. A hydrological transport coefficient of 6.3E-9 is chosen, as used in Reference 2.

At what annual rate of total protons does the surface water activity hit 100% of either the tritium or sodium groundwater limit?

Sodium-22 proves to be the limiting factor, at 7.75E19 protons per year, which represents about 4.8 million pulses of full Linac intensity, or a continuous operation rate of about 553 pulses per hour all year long (Appendix 2).

Experiment Mode Surface Water

For experiment mode operation, the emittance absorber will be retracted out of the beam. Up to 60 pulses per hour of beam, with up to 1.6E13 protons per pulse, will be transported into experimental apparatus downstream of the emittance absorber.

In order to estimate surface water activity, as a "strawman" Igor Rakhno used MARS to simulate a typical thick apparatus that absorbs the entire beam. He calculated star density in soil around the enclosure. This analysis is specific to the strawman model, but can serve to give a rough order of magnitude that may be expected for other experimental devices.

The configuration simulated consisted of the Muons, Inc. High-Pressure RF Cavity, which is steel, upstream of a cylindrical absorber 5.5 inches (14 cm) in diameter and 4 inches (10 cm) long. The MTA solenoid magnet was ignored; the cavity and absorber were presumed to be unshielded.

Igor Rakhno wrote on 7 April 2010: "The S_{max} approximately = 430 star/cm^3-sec for rep.rate 1 pulse/min." Converting to the units used in the model, this value corresponds to

S_{max} = (430 stars/cm^3-sec)/[(1/60 pulses per second)*(1.6E13 p/pulse)]
= 1.61E-9 stars per incident proton per cubic centimeter.

Igor points out that the cavity and absorber represent more material in the transverse directions than does the emittance absorber, so the star density in the soil is correspondingly lower.

At what annual rate of total protons does the surface water activity hit 100% of the 2000-pCi annual limit?

The result is about 6.7E20 protons per year (Appendix 3). This represents about 42 million pulses of full Linac intensity, or a continuous rate of about 4780 pulses per hour.

Planned operation of beam to experiments will entail up to 60 pulses per hour. For the strawman apparatus in this example, this mode will thus lie well within limits set by surface water activity. For example, 168 hours per week at 60 pulses per hour and 1.6E13 protons per pulse would be 8.4E18 protons per year.

This example included a "thick" experiment that absorbs essentially all the beam. "Thin" apparatus, where a substantial fraction of the incident beam does not interact, is not considered here.

Surface water concentrations will need to be evaluated in detail for any particular configuration of experimental apparatus. The Radiation Safety Officer will consider such evaluations in determining the operational requirements for an experiment.

Experiment Mode Groundwater

To find the hypothetical effect on groundwater, again assuming that the drainage system does not flush radionuclides into surface water, again choosing a hydrological transport coefficient of 6.3E-9, one may ask: For the strawman apparatus, at what annual rate of total protons does the surface water activity hit 100% of either the tritium or sodium groundwater limit?

Once again, sodium-22 proves to be the limiting factor, at 1.77E20 protons per year, which represents about 11 million pulses of full Linac intensity, or a continuous operation rate of about 1263 pulses per hour all year long (Appendix 4).

Final Absorber and Groundwater

The final absorber, buried in the berm beyond the downstream wall of the MTA enclosure, is designed to absorb high beam intensities.

There was no granular underdrainage installed in this region. Instead water percolates into the soil around and below the absorber. Therefore surface water limits are not relevant.

For the hydrological transport coefficient, or "R," we select 6.3E-9, the value used for groundwater transport in Reference 2.

The star density for the absorber, also taken from Reference 1, is an average (or S_{ave}) of 2.71E-11 stars per cubic centimeter per incident proton. Note that this is an *average*, not a peak star density; the groundwater model spreadsheet allows either type of input.

At what annual rate of total protons does the groundwater hit 100% of either the tritium limit or the sodium limit?

The result is approximately 2.01E20 protons per year for the sodium limit, equivalent to 12.6 million pulses at full Linac intensity, or a continuous rate of about 1430 pulses per hour (Appendix 5).

Operation of the MuCOOL beamline in experiment mode at 60 pulses per hour will produce groundwater concentrations well below this limit. As mentioned above, fewer than 8.4E18 protons per year can be delivered at this rate.

References:

1. J. D. Cossairt, A. J. Elwyn, P. Kesich, A. Malensek, N. Mokhov, and A. Wehmann,"The Concentration Model Revisited," Environmental Protection Note EP-17, 24 June 1999.

2. Kamran Vaziri, Paul Kesich, Igor Rakhno, and Carol Johnstone, "Surface and Groundwater Assessment of the MuCOOL Beam Absorber," April 2003.

Appendices:

1. Emittance Absorber Groundwater 06-24-10.xls, worksheet "Emittance Surface Water"

2. Emittance Absorber Groundwater 06-24-10.xls, worksheet "Emittance Ground Water"

3. High Pressure RF Cavity Groundwater 04-07-10.xls, worksheet "Exp Surface Water"

4. High Pressure RF Cavity Groundwater 04-07-10.xls, worksheet "Exp Groundwater"

5. Mucool Final Absorber Groundwater.xls